

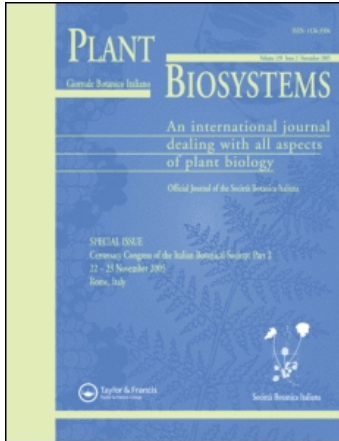
This article was downloaded by: [Montagnoli, Antonio]

On: 5 August 2010

Access details: Access Details: [subscription number 925198057]

Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title-content=t713737104>

### Root seasonal pattern, spatial distribution, and C:N ratio of matgrass pasture (*Nardus stricta* L.) in the Lombardy Prealps

A. Montagnoli<sup>a</sup>; A. Di Iorio<sup>b</sup>; R. M. Ceriani<sup>c</sup>; G. S. Scippa<sup>d</sup>; D. Chiatante<sup>b</sup>

<sup>a</sup> Dipartimento di Scienze Chimiche ed Ambientali, Università dell'Insubria, Italy <sup>b</sup> Dipartimento di Biologia Funzionale e Strutturale, Università dell'Insubria, Italy <sup>c</sup> Centro Flora Autoctona della Regione Lombardia, Parco del Monte Barro, Italy <sup>d</sup> Dipartimento di Scienze e Tecnologie per l'Ambiente e Il Territorio, Università del Molise, Italy

Online publication date: 04 August 2010

**To cite this Article** Montagnoli, A. , Di Iorio, A. , Ceriani, R. M. , Scippa, G. S. and Chiatante, D.(2010) 'Root seasonal pattern, spatial distribution, and C:N ratio of matgrass pasture (*Nardus stricta* L.) in the Lombardy Prealps', Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 144: 2, 463 — 470

**To link to this Article:** DOI: 10.1080/11263501003731979

**URL:** <http://dx.doi.org/10.1080/11263501003731979>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

**A SELECTION OF PAPERS PRESENTED DURING THE 7TH ISSR SYMPOSIUM, ROOT RESEARCH AND APPLICATION (ROOT-RAP), 2–4 SEPTEMBER 2009**

**Root seasonal pattern, spatial distribution, and C:N ratio of matgrass pasture (*Nardus stricta* L.) in the Lombardy Prealps**

A. MONTAGNOLI<sup>1</sup>, A. DI IORIO<sup>2</sup>, R. M. CERIANI<sup>3</sup>, G. S. SCIPPA<sup>4</sup>, & D. CHIATANTE<sup>2</sup>

<sup>1</sup>Dipartimento di Scienze Chimiche ed Ambientali, Università dell'Insubria, Italy, <sup>2</sup>Dipartimento di Biologia Funzionale e Strutturale, Università dell'Insubria, Italy, <sup>3</sup>Centro Flora Autoctona della Regione Lombardia, Parco del Monte Barro, Italy, and <sup>4</sup>Dipartimento di Scienze e Tecnologie per l'Ambiente e Il Territorio, Università del Molise, Italy

**Abstract**

The aim of the present study was to investigate carbon and nutrient cycling and the role of root dynamics in terrestrial ecosystems such as large abandoned pastures and natural grasslands present in the Prealps, for which below-ground processes are currently enigmatic. In particular, we quantified root/leaf biomass and C:N ratio throughout two growing seasons. Additionally, root traits such as root length density (RLD), root mass density (RMD), and root diameter classes (RDC) were also investigated with the aim of understanding the spatial distribution of roots in the soil. In our samples, we found that the roots could be divided into three main diameter classes and hence quantified the presence of each class along the soil profile. With regard to total root biomass, we found the occurrence of two peaks of biomass accumulation during the growth season, and when biomass accumulation was compared with climatic data, it was impossible to obtain a clear indication of the root turnover rate. In fact, the strong influence of grazing on the above-ground biomass could have affected, in turn, root biomass. In future, this possible complication will be avoided by repeating the measurements within enclosures to avoid grazing interference. We found that C:N ratio remained constant, with a single peak, suggesting a lower root decomposition during the warmest period (August 2006). The concentration of nitrogen in roots decreased with depth as a result of a decrease in roots with smaller diameters. The reverse was found for carbon content, which increased with depth, probably due to an increase in roots with larger diameters. This study represents the first attempt to estimate root turnover rates in this prealpine ecosystem, which have been analysed to date only for the above-ground biomass.

**Keywords:** *Root seasonal pattern, soil distribution, C:N ratio, Nardus stricta L.*

**Introduction**

The atmospheric concentration of carbon dioxide (CO<sub>2</sub>) has increased by 31% since 1750. The present CO<sub>2</sub> concentration has not been observed for the past 420,000 years and probably not for the past 20 million years. The current rate of increase is unprecedented for, at least, the past 20,000 years. About three-quarters of the anthropogenic emissions of CO<sub>2</sub> into the atmosphere for the past 20 years is due to the combustion of fossil fuels. The remainder is predominantly due to land-use changes, especially deforestation (Petit et al. 1999; IPCC 2001). Terrestrial ecosystems are constantly responding to an ever-fluctuating variety of biotic and abiotic influences. Uncertainty remains as to whether the increasing

anthropogenic CO<sub>2</sub> is sequestered temporarily in oceans and the terrestrial biosphere (Francey et al. 1995). Understanding how ecosystems respond to simultaneous increase in atmospheric CO<sub>2</sub> and temperature, and how they will react in the future, is necessary. Predicting the future response depends on how the effects of rising temperature and CO<sub>2</sub> are represented in climate models (Norby & Jackson 2000), thus requiring a collection of as much data as possible. In fact, one of the main limitations for the certainty of climate models is the collection of suitable ground data from the terrestrial biosphere, because of the great variation in vegetation type, the strong dependence on local conditions (soil moisture, temperature, precipitation, etc.) (Fitter et al. 1998; Atkin et al. 2000; Eissenstat et al. 2000; Joslin

et al. 2000; Pregitzer et al. 2000; Pendall et al. 2004), and the wide variability within an individual species (Eissenstat & Yanai 1997). Estimation of the capacity of forests and grasslands to sequester carbon (C) in a CO<sub>2</sub>-enriched atmosphere and the response of communities to changing water and temperature regimes and nitrogen deposition must take into account below-ground processes (Norby & Jackson 2000). Plants spend a considerable proportion of the energy that they gain during photosynthesis on the production and maintenance of roots and so primary production allocated below ground is often greater than that allocated above ground (Reichle et al. 1973; Nadelhoffer & Raich 1992). Fine roots (with diameter  $d < 2$  mm) (Kurz 1989) represent a small part of the total root biomass, but they play a very important role in the global carbon budget. A plant that maintains roots for a longer period (i.e. has lower turnover rates) allocates less carbon to the production of new roots, but expends more energy in maintaining roots (i.e. root respiration) and hence may be less efficient at nutrient uptake compared with a root newly deployed in a nutrient-rich micro site. When roots die and decompose, some of their carbon content is released into the atmosphere and some may remain as soil organic matter (SOM). Fine roots are the primary pathway for water and nutrient uptake by plants and provide the interface between living tissue and surrounding soil, including exudates, secretions, and sloughed-off cells. Moreover, rhizo-deposition supports microbial communities, which constitute primary elements for the nutrient cycling processes in the soil (Caldwell & Richards 1986; Van Veen et al. 1991; Nadelhoffer & Raich 1992; Ross et al. 1995; Jackson et al. 1997; Paterson et al. 1997). Hence, fine root dynamics is a major determinant of the capacity of an ecosystem to sequester atmospheric carbon. Tissue carbon and nitrogen content also affect nutrient cycling. Indeed, estimation of carbon and nitrogen values could allow a better understanding of root dynamics as the overall C:N ratio is strictly related to the rate at which SOM and litter decompose. With increased C:N ratios, forage quality for insects is reduced. Moreover, the lower specific rates of root activity are inversely related to greater carbon:nutrient ratios in conjunction with decreased tissue concentrations of nutrients, including nitrogen and potassium (Israel et al. 1990; Newbery et al. 1995; Hodge et al. 1998), and in general, rates of ATP production (a function of respiration rate) are linearly related with an increase in tissue nitrogen concentration, proteins, and carbohydrates (Ryan 1991; Pregitzer et al. 1993; Ryan et al. 1996; Van der Westhuizen & Cramer 1998). Basic data on root processes have been acquired for different forest ecosystems, but little attention has been paid to the carbon budget of

grasslands. The aim of this study was to estimate the root biomass and C:N ratio during the entire growing season for a matgrass pasture (*Nardus stricta* L.). The above-ground biomass was also measured in order to determine whether it was related to the below-ground biomass. Additionally, the root depth distribution (root length density [RLD] and root mass density [RMD]), morphological parameters (diameter classes), and C:N ratios were measured along the soil profile in order to understand the spatial distribution of carbon and nitrogen. The biomass pattern was compared with climatic data, with particular attention to the annual rainfall pattern.

## Materials and methods

The study area is located in the catchments of Telo stream in the Lombardy Prealps (Intelvi Valley, Como province, NW Italy) approximately 45°59'N 9°07'E and 1000 m above sea level, close to Lakes Como and Lugano. In the Lombardy Prealps, historical land use has created extensive pastures that, together with the natural grasslands, represent an important land cover category. In particular, the matgrass (*Nardus stricta* L.) pastures cover more than 23% of the total public vegetation (land cover data from Cosorzio Forestale Lario Intelvese, Comunità Montana Valle Intelvi). The number of species is approximately 28 and the dominant species are *Nardus stricta* L. (25%), *Festuca varia* Haenke s.l. (20%), and *Carex pilulifera* L. (11%) (Table I). The climate is subtropical, mean annual precipitation is 1600 mm (weather data from Consorzio dell'Adda, Lombardy, 1998–2007), occurring in two main periods (March–April and October–November), and a mean annual temperature of 10–11°C. The soil type is a Leptosol according to the World Reference Base for Soil Resources (WRB) (FAO/ISRIC/ISSS, 1998) (data from ERSAF, Lombardy), with a depth of 40–50 cm and frozen from late October to April. A core sampling method (Vogt & Persson 1991) was used to make quantitative determinations of the root system. The samples were collected on a hill (Alpe di Ponna), with a mean slope of 25°, except on the southern side, where the species were not representative (Table I, survey number 5). Three soil core samples (8 cm [diameter] × 15 cm [depth]) were collected on each sampling date, using a hand plant root sampler with a drilling crow that can take undisturbed soil samples (Eijkelkamp Agrisearch Equipment: *Plant Root Sampling* model P1.30). Soil cores were randomly collected, with a minimal distance of 15 m between each sample. The biomass sampling was conducted monthly from August to October 2006 and from April to October 2007, when the soil was free of snow cover and completely unfrozen. In total,

Table I. Phytosociological relevés of the study sites using the estimation scale of land cover percentage according to Braun-Blanquet (1964): (-) = species absent, + = <1%, 1 = 1–5%, 2 = 5–25%, 3 = 25–50%, 4 = 50–75%, 5 = 75–100%. Values in the table are percentage of the total.

No.	1	2	3	4	5
COV% Layer Grass	85	90	80	90	85
COV% Layer Moss	80	75	60	60	20
N Species	31	31	26	26	28
Name-SPE	-	-	-	-	-
<i>Achillea roseo-alba</i> Ehrend.	+	+	.	+	+
<i>Agrostis canina</i> L.	6	1	15	15	5
<i>Ajuga reptans</i> L.	.	10	+	.	.
<i>Anthoxanthum odoratum</i> L.	5	5	5	+	.
<i>Arnica montana</i> L.	.	.	+	.	.
<i>Avenella flexuosa</i> (L.) Parl.	25	25	25	20	+
<i>Calluna vulgaris</i> (L.) Hull	.	15	25	.	+
<i>Campanula barbata</i> L.	.	+	+	+	.
<i>Carex caryophyllea</i> La Tourr.	1	.	5	.	+
<i>Carex leporina</i> L.	+	10	.	+	.
<i>Carex pilulifera</i> L.	50	20	20	20	5
<i>Carlina acaulis</i> L.	.	.	.	.	+
<i>Cerastium fontanum</i> Baumg.	r	r	+	+	.
<i>Crataegus monogyna</i> Jacq.	.	r	.	.	.
<i>Cynosurus cristatus</i> L.	.	.	.	.	1
<i>Dactylis glomerata</i> L.	.	.	.	.	+
<i>Danthonia decumbens</i> (L.) DC.	15	10	20	10	10
<i>Dianthus superbus</i> L. cfr.	.	.	.	.	5
<i>Euphrasia</i> sp.	.	.	.	r	.
<i>Festuca varia</i> Haenke s.l.	50	50	50	50	60
<i>Galium album</i> Miller	+	.	.	.	.
<i>Genista tinctoria</i> L.	15	15	10	10	+
<i>Gentiana kochiana</i> Perr.et Song.	+	.	.	.	.
<i>Geum urbanum</i> L.	r	+	+	.	.
<i>Hieracium auricula</i> Lam.et DC.	5	20	5	10	+
<i>Hieracium pilosella</i> L.	5	20	15	5	5
<i>Hieracium sylvaticum</i> (L.) L.	5	+	+	+	.
<i>Homogyne alpina</i> (L.) Cass.	+	+	+	+	.
<i>Leontodon hispidus</i> L.	.	+	.	.	1
<i>Lotus corniculatus</i> L.	+	.	.	.	.
<i>Luzula multiflora</i> (Ehrh.) Lej.	25	10	10	5	+
<i>Nardus stricta</i> L.	60	75	50	60	40
<i>Plantago alpina</i> L.	+	+	.	.	+
<i>Plantago media</i> L.	r	.	.	.	.
<i>Polygala chamaebuxus</i> L.	1	15	10	+	+
<i>Potentilla aurea</i> L.	10	5	1	+	+
<i>Potentilla erecta</i> (L.) Rauschel	20	15	5	15	.
<i>Prunella grandiflora</i> (L.) Scholler	+	.	.	+	+
<i>Ranunculus montanus</i> Willd. s.l.	.	+	+	+	.
<i>Rumex acetosella</i> L.	.	.	.	.	2
<i>Solidago virgaurea</i> L.	+	10	5	10	.
<i>Stachys officinalis</i> (L.) Trevisan	.	.	.	.	+
<i>Thymus pulegioides</i> L.	.	.	.	.	20
<i>Trifolium pratense</i> L.	.	.	.	.	+
<i>Trifolium repens</i> L.	+	10	.	+	+
<i>Veronica officinalis</i> L.	1	+	5	5	+
<i>Viola tricolor</i> L.	r	+	.	.	.

r (seldom, insignificant cover); + (solitary, insignificant cover).

cores were collected on 10 dates, making a total of 30 cores for the study. The entire above-ground biomass was previously collected, from the circled area of the sampler, stored in a plastic box, and during the same day, oven-dried at 105° for 24 h and weighted. The soil samples were stored in plastic boxes at 4°C until processed. Each sample was washed carefully over a 1-mm sieve and all roots were collected using forceps. Then, the roots were dried as mentioned above. Root distribution, water content, and soil bulk density were measured as a function of soil profile (depth). In May 2007, a series of soil cores (size: 5 cm [diameter] × 5.5 cm [depth]) were taken from different soil depths (10-cm-deep soil layers for a total depth of 40 cm). Five replicate samples were made, resulting in a total of 20 samples. The roots freed from the soil were scanned at a scanning resolution of 400 dpi and then oven-dried and weighted. The images were analysed by the software WinRhizo Pro V. 2007d (Regent Instruments Inc., Quebec) in order to obtain the morphological data. Gravimetric water content and bulk density of the same soil samples were measured. Water content was calculated as percentage of the dry weight. The soil bulk density was calculated as follows: mass of dry soil (g) – mass of rocks (g)/soil core volume (cm<sup>3</sup>) – volume of rocks (cm<sup>3</sup>). Root nitrogen and carbon contents were determined by a CHN analyser (NA-2000 N-Protein, Fisons Instruments S.p.A., Rodano, Italy).

## Results

The seasonal patterns of above- and below-ground biomass in relation to the yearly rainfall pattern are

shown in Figure 1. Root biomass reached the highest value ( $2269.3 \pm 153.84 \text{ g m}^{-2}$ ) in August 2006, decreasing strongly to 41% in October 2006 ( $939.0 \pm 129.15 \text{ g m}^{-2}$ ). Leaf biomass showed the same trend, going from the highest value of  $326.8 \pm 131.65 \text{ g m}^{-2}$  in August 2006 to  $21.9 \pm 8.78 \text{ g m}^{-2}$  in October 2006, with a decrease of 6.68%. In April 2007, root and leaf biomass values were  $660.7 \pm 140.68 \text{ g m}^{-2}$  and  $15.05 \pm 14.86 \text{ g m}^{-2}$ , respectively, approximately the same measured in October the previous year (i.e. 2006). Both leaf and root biomass showed increases at the beginning of the 2007 growth season. In particular, the root biomass increased strongly from April ( $660.67 \pm 140.68 \text{ g m}^{-2}$ ) to May 2007 ( $1570.28 \pm 467.10 \text{ g m}^{-2}$ ) and then exhibited a continuous decrease until the end of the season, with the only exception of June–July ( $952.20 \pm 320.45 \text{ g m}^{-2}$  to  $910.36 \pm 237.64 \text{ g m}^{-2}$ ) and September–October ( $280.23 \pm 180.16 \text{ g m}^{-2}$  to  $302.02 \pm 26.70 \text{ g m}^{-2}$ ), when the values did not differ. The above-ground biomass showed a small increase from April ( $15.05 \pm 14.86 \text{ g m}^{-2}$ ) to July 2007 ( $39.51 \pm 46.48 \text{ g m}^{-2}$ ), but the high standard deviation values suggest no real increment. Then, from July to August 2007 ( $246.06 \pm 30.40 \text{ g m}^{-2}$ ), the above-ground biomass became six-fold greater, suggesting a strong influence of herbivore pressure. From August to September ( $87.46 \pm 17.42 \text{ g m}^{-2}$ ) and in October ( $27.88 \pm 7.11 \text{ g m}^{-2}$ ), the biomass reverted to the same values measured the previous year (i.e. 2006). The soil bulk density and water content were remarkably similar along the soil profile, as shown in Table II. However, the rooting depth data (RLD and RMD) showed a decrease along the soil profile (Figure 2). In total, 83% of

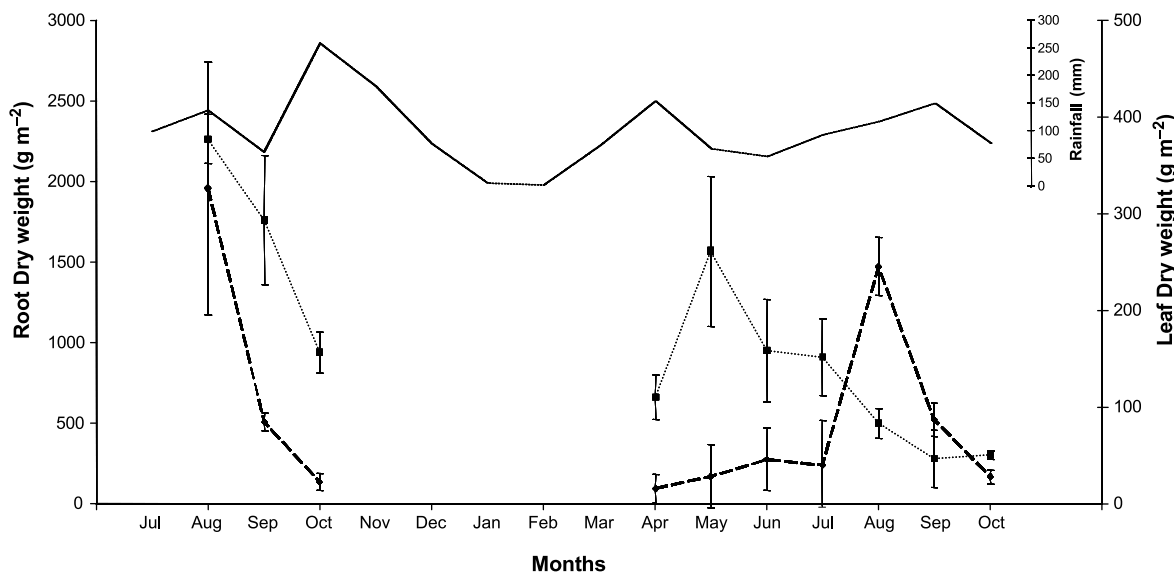


Figure 1. Root and leaf dry biomass from August 2006 to August 2007 of *Nardus stricta* in matgrass pasture located in the Lombardy Prealps. Dotted line (.....) refers to root biomass, dashed line (- - -) refers to leaf biomass, and continuous line (—) refers to monthly rainfall. Values are mean of three replicates  $\pm$  1SD.

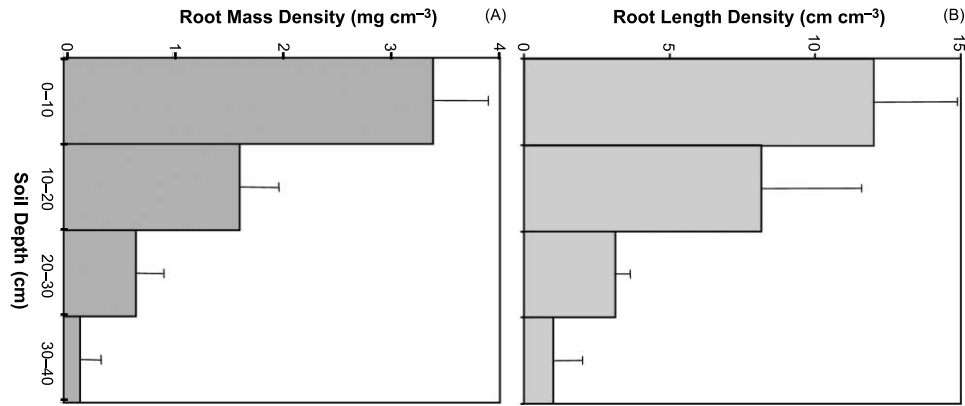


Figure 2. Root dry mass density (A), and root length density (B) at different soil depths for *Nardus stricta*. Values are mean of five replicates ± 1SD.

RLD and 86% of RMD occurred in the first 20 cm of soil. The root morphological analysis showed three main diameter classes, as represented by the three peaks in Figure 3. Roots with smaller diameters were more frequent in the shallow soil layer (from 0 to 10 cm), whereas roots with larger diameters were most concentrated in the deeper soil layers. The C:N ratio in root tissues remained

constant throughout the growing season, with values between 20:1 and 30:1 (Table III). Only during August 2007, the value was higher than 30:1 ( $34.76 \pm 6.12$ ), in contrast with the continuous decrease in root dry biomass. Nitrogen concentration in roots decreased with depth, while carbon content showed a reverse pattern, increasing from surface to deeper soil layers (Figure 4).

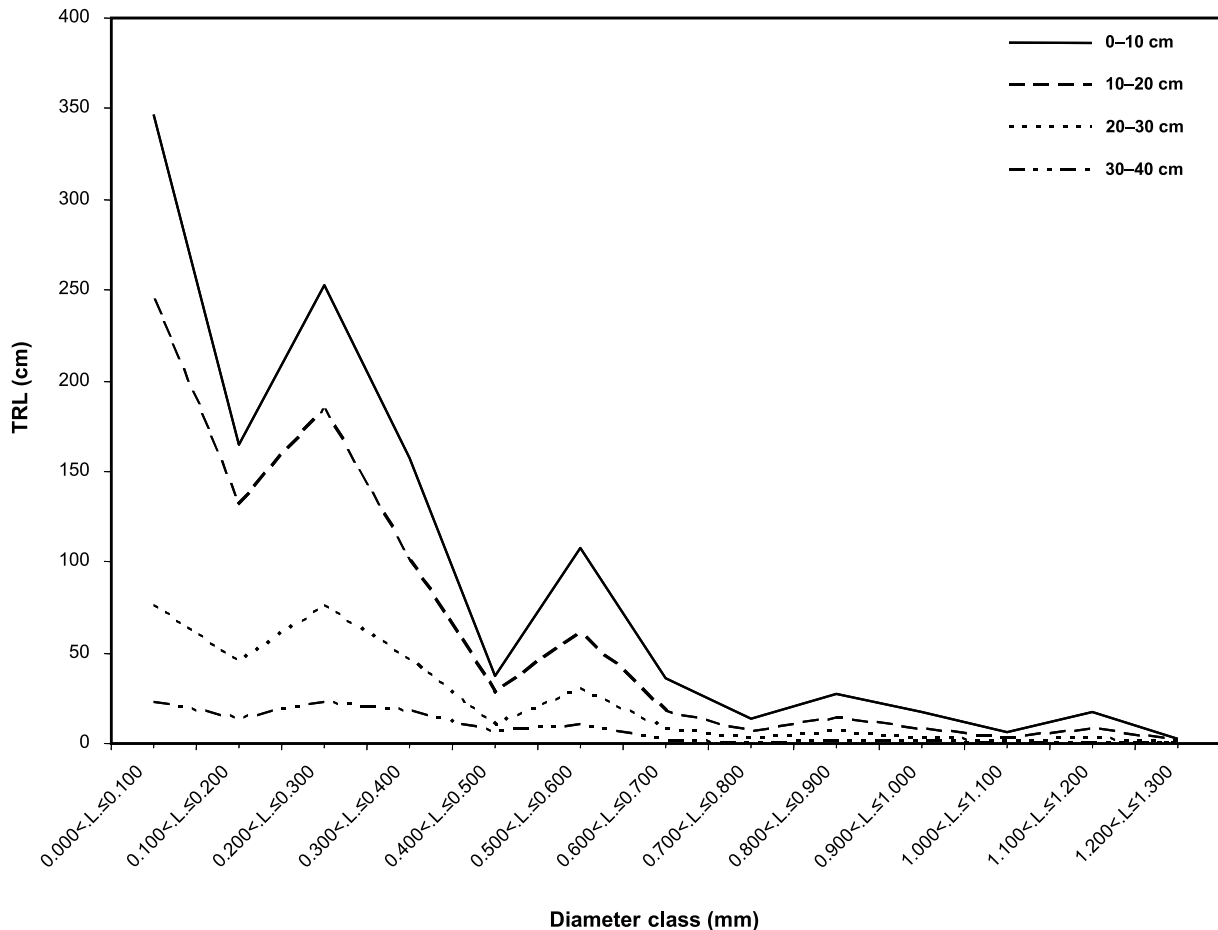


Figure 3. Total root length (TRL) per 0.1-mm diameter resolution class for different soil depths of *Nardus stricta* plants grown in matgrass pasture located in the Lombardy Prealps. Values are mean of five replicates.



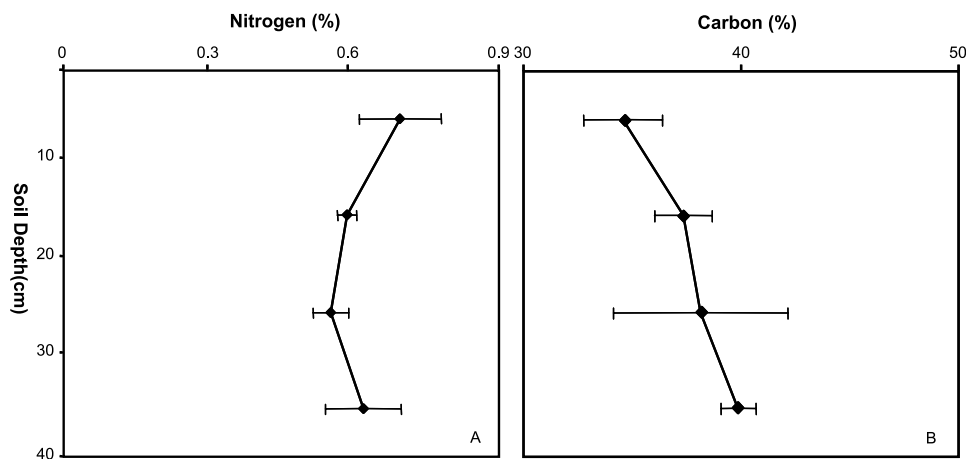


Figure 4. Root nitrogen (A) and carbon (B) tissue content at different soil depths for *Nardus stricta*. Values were calculated by multiplying nitrogen and carbon concentration of composite root samples of each depth class by the corresponding mean dry matter. Samples were collected in May 2007. Values are mean of three replicates  $\pm 1$  SD.

Table II. Soil bulk density and gravimetric soil moisture along the soil profile. Samples were collected in May 2007. Values are mean of five replicates  $\pm 1$  SD.

Soil depth (cm)	Soil bulk density (g cm <sup>-3</sup> )	Soil moisture (%)
5	0.63 $\pm$ 0.13	24.11 $\pm$ 3.27
15	0.69 $\pm$ 0.11	34.18 $\pm$ 5.42
25	0.74 $\pm$ 0.16	35.31 $\pm$ 9.18
35	0.78 $\pm$ 0.17	35.92 $\pm$ 6.66

Table III. Total nitrogen and carbon content and C:N ratio in the *Nardus stricta* root tissues from August 2006 to August 2007. Values are mean of three replicates  $\pm 1$  SD.

Sampling months	Nitrogen (%)	Carbon (%)	C:N ratio
August 2006	1.67 $\pm$ 0.25	39.29 $\pm$ 0.47	23.97 $\pm$ 3.52
September	1.67 $\pm$ 0.12	38.57 $\pm$ 2.55	23.98 $\pm$ 3.17
October	1.23 $\pm$ 0.07	33.22 $\pm$ 3.47	26.91 $\pm$ 1.85
April	1.56 $\pm$ 0.17	30.64 $\pm$ 2.63	19.92 $\pm$ 3.06
May	1.56 $\pm$ 0.12	32.71 $\pm$ 5.24	20.23 $\pm$ 1.94
June	1.50 $\pm$ 0.15	32.71 $\pm$ 4.71	21.84 $\pm$ 3.19
July	1.53 $\pm$ 0.17	30.77 $\pm$ 2.04	20.21 $\pm$ 1.06
August 2007	0.84 $\pm$ 0.13	28.63 $\pm$ 2.05	34.76 $\pm$ 6.13

## Discussion

Comparing the seasonal patterns of root/leaf biomass with the amount of rainfall, we observed that the higher plant growth is strictly related to the vernal rainfall and temperature rise, whereas from August to October, high rainfall and lower temperatures cause a general decline in biomass. These findings are in agreement with the pattern of spring growth and autumnal die-back typical of *Nardus stricta* (Perkins 1968). The above- and below-ground biomass data showed differences in biomass build-up. The pattern of biomass production suggests the

existence of one main growing period, corresponding to the summer season (July–August), when the seasonal mean rainfall is lower than the annual mean, indicating a stronger dependence on irradiance and temperature. Moreover, the low leaf biomass values measured during the spring season (April–May) are probably due to the grazing activity. The analysis of the fluctuating root biomass patterns and the rainfall patterns shows a lack of any relationship except for the April–May period, when root biomass reached its peak and showed a positive relationship with rainfall, with a slight shift in time. Below-ground biomass was negatively correlated with air temperature, as previously reported by Karunaichamy (1992). Brown (1943) noted that both roots and rhizomes of blue grass (*Poa bulbosa* L.) usually lost weight during the summer season at mean temperatures near or above 26.6°C (80°F). Accordingly, in our study, the seasonal variation in root biomass could be due to the combined effects of soil moisture and elevated air temperature, which could lead to an increase in root respiration and soil microbial decomposition activity, with the consequent decrease in root biomass. Another possible reason for the decrease may be the cow grazing activity, its direct effect on the root development (e.g. through trampling), and the increase in soil carbon and nitrogen due to animal droppings. Root morphology along the soil profile was measured during the spring flush before the summer drought period in order to be representative of the maximum rooting depth. Most of the roots were located in the first 10–20 cm of the soil, a common pattern for the majority of the herbaceous plants in the world (Jackson et al. 1996). In total, 60% of the total RMD and 50% of the RLD were found within the first 5 cm of soil, and 83% of RDL and 86% of RMD within the first 20 cm, indicating a greater

concentration of root biomass in the superficial organic layers and a consequent exponential decline with depth. As is well known, fine root morphology is strongly affected by soil characteristics (Pregitzer et al. 1998; Eissenstat et al. 2000). We observed no differences in soil bulk density (with values lower than  $1 \text{ g cm}^{-3}$ ) relative to depth, indicating an open friable soil with good organic matter content for the whole soil profile. Furthermore, we measured an increase in water content from the top 10 cm of the soil up to 20 cm, followed by constant values for the deeper soil layers (25–35 cm). The high root concentration in the top 10 cm of the soil could then be a result of the greater nutrient availability in the upper soil layer (Jackson et al. 1996). The data on root diameter showed three main diameter classes, together with an increase in mean root diameter with depth. Roots with smaller diameters ( $d < 0.2 \text{ mm}$ ) were found mainly in the upper soil layer (0–10 cm), while the percentage of roots with larger diameters ( $0.2 \text{ mm} < d < 0.6 \text{ mm}$ ) increased with depth; only roots with diameters greater than 0.6 mm tended to decrease with depth. These data suggest an unequal development of the root system, with greater biomass and small root size occurring in the upper soil layer, and a smaller biomass and larger root size in deeper soil layers. These results reinforce the idea that nutrient availability in soil affects root biomass distribution and root morphology. Finer roots are directly involved in nutrient uptake and are in fact more frequent where nutrients are more available, thus decreasing constantly in frequency with depth. On the other hand, roots with larger diameters ( $0.2 \text{ mm} < d < 0.6 \text{ mm}$ ) should act primarily as carbon storage organ, thus increasing in frequency with depth. Finally, roots with diameters  $> 0.6 \text{ mm}$  provide plant anchorage (Hummel et al. 2007) and, therefore, occur in the top soil. A low C:N ratio (below 25–28:1) in organic matter favours tissue decomposition by microbial activity (Lincoln et al. 1986). In our study, the constant value of nitrogen content measured during the growing season may indicate the occurrence of net immobilization of fine roots decomposition (Bartholomew 1965), suggesting that variations in roots biomass could be due to either the production of new roots or the growth of already existing ones. The minimum values for carbon and nitrogen content ( $\text{C} = 28\%$ ;  $\text{N} = 0.84\%$ ) and the consequent highest C:N ratios were measured in late summer 2007, indicating a very slow root decomposition rate in spite of the low root biomass observed in the same period. This may be related to cow grazing and the consequent enrichment of the soil with nitrogen, which could in turn fulfil the microbial needs in order to support the decomposition activity. Despite the unfavourable root C:N ratio,

decomposition could continue, inducing the observed reduction in the root biomass. Also, the root nitrogen content decreased with depth, while the carbon content increased. The higher nitrogen concentration in roots collected from the uppermost soil layer (0–10 cm) might be ascribed to the higher percentage of finer roots ( $d < 0.2 \text{ mm}$ ), where a greater protein content is associated with nutrient uptake (e.g. protein pumps, transmembrane channel, enzymes, etc.). The reverse pattern observed for the carbon concentration (higher in deeper roots) might be related to the higher percentage of thicker roots ( $0.6 \text{ mm} < d < 1.3 \text{ mm}$ ), where storage occurs.

### Conclusion

Root decomposition often plays a key role in soil carbon sequestration and nutrient cycling, while carbon and nutrient dynamics associated with root decay represent significant components of the global carbon cycle. This study has shown that matgrass pasture can act as a significant sink of carbon accounting, during its annual growth of  $8.1 \text{ Mg ha}^{-1}$  of total dry mass, of which more than 91% ( $7.4 \text{ Mg ha}^{-1}$ ) is accumulated below ground. Moreover, our data showed that the local climate conditions (temperature and rainfall) can have a large impact on rates of root production. Unfortunately, we did not collect data about the nutrient concentration in the soil layer, but root biomass and architecture seem to be strongly related to the availability of different nutrients along the soil profile. Finally, the root decomposition rate inferred from the tissue C:N content data showed a great inconsistency with the biomass values. Especially, where the C:N ratio reached higher values (above 28–30) associated with a lower decomposition rate, the biomass measured was lower than expected. These observations indicate the need of sampling in areas where grazing is artificially excluded to avoid nitrogen input due to animal droppings. A more thorough understanding of the factors that control root decomposition will improve our ability to model global carbon dynamics and predict the effects of future climate and other global changes on biogeochemical cycles.

### Acknowledgements

This research was supported by the Italian MIUR (Ministero dell'Istruzione dell'Università e della Ricerca) and by EU ECOSLOPES project (QLK5-2001-00289). The authors also acknowledge Dr Simon Pierce (University of Insubria, Varese) for revisiting the text and helping in taking root cores in the field. A special recognition to Dr Rosamaria



Lazzaroni for the help in the field work and root digital data analysis.

## References

- Atkin OK, Edwards EJ, Loveys BR. 2000. Response of root respiration to changes in temperature and its relevance to global warming. *New Phytol* 147: 141–154.
- Bartholomew WV. 1965. Mineralization and immobilization of nitrogen in the decomposition of plant and animal residues. In: Bartholomew WV, Clark FE, editors. *Soil nitrogen*. Madison: American Society of Agronomy. pp. 285–306.
- Braun-Blanquet J. 1964. *Pflanzensoziologie. Grundzüge der Vegetationskunde*. 3. Aufl. Wien: Springer-Verlag.
- Brown EM. 1943. Seasonal variation in the growth and chemical composition of Kentucky bluegrass. *Missouri Agric Exp Stat Bull* 360: 56.
- Caldwell MM, Richards JH. 1986. In: Givnish TJ, editor. *On the economy of plant form and function*. Cambridge: Cambridge University Press. pp. 251–273.
- Eissenstat DM, Wells CE, Yanai RD, Whitbeck JL. 2000. Building roots in a changing environment: Implications for root longevity. *New Phytol* 147: 33–42.
- Eissenstat DM, Yanai RD. 1997. The ecology of root lifespan. *Adv Ecol Res* 27: 1–60.
- Fitter AH, Graves JD, Self GK, Brown TK, Bogie DS, Taylor K. 1998. Root production, turnover and respiration under two grassland types along an altitudinal gradient: Influence of temperature and solar radiation. *Oecologia* 114: 20–30.
- Francey RJ, Tans PL, Allison CE, Enting IG, White JWC, Trolier M. 1995. Changes in oceanic and terrestrial carbon uptake since 1982. *Nature* 373: 326–330.
- Hodge A, Stewart J, Robinson D, Griffiths BS, Fitter AH. 1998. Root proliferation, soil fauna and plant nitrogen capture from nutrient-rich patches in soil. *New Phytol* 139: 479–494.
- Hummel I, Vile D, Violle C, Devaux J, Ricci B, Blanchard A, et al. 2007. Relating root structure and anatomy to whole-plant functioning in 14 herbaceous Mediterranean species. *New Phytol* 173: 313–321.
- IPCC. 2001. In: Houghton J-T, Ding Y, Griggs D-J, Noguer M, Van der Linden P-J, Dai X, et al., editors. *Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. p. 881.
- Israel DW, Rufty TW, Cure JD. 1990. Nitrogen and phosphorus nutritional interactions in a CO<sub>2</sub> enriched environment. *J Plant Nutrition* 13: 1419–1433.
- Jackson RB, Canadell J, Ehleringer JR, Mooney HA, Sala OE, Schulze ED. 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia* 108: 389–411.
- Jackson RB, Mooney HA, Schulze ED. 1997. A global budget for fine root biomass, surface area, and nutrient contents. *Proc Natl Acad Sci USA* 94: 7362–7366.
- Joslin JD, Wolfe MH, Hanson PJ. 2000. Effects of altered water regimes on forest root systems. *New Phytol* 147: 117–129.
- Karunaichamy K. 1992. *Biomass dynamics and nutrient composition in grazing land ecosystem of Western Ghats region of Tamil Nadu*. Ph.D. thesis, Madurai Kamaraj University, Madurai.
- Kurz WA. 1989. Significance of shifts in carbon allocation patterns for long-term site productivity research. In: Dyck WJ, Mees CA, editors. *Proceedings of the IEA/BE A3 Workshop, "Research strategies for long term site productivity"*, report no. 8, August 1998, Seattle, WA. New Zealand Forest Research Institute Bulletin 152.
- Lincoln DE, Couvet D, Sionit N. 1986. Response of an insect herbivore to host plants grown in carbon dioxide enriched atmospheres. *Oecologia* 69: 556–560.
- Nadelhoffer K-J, Raich JW. 1992. Fine root production estimates and belowground carbon allocation in forest ecosystems. *Ecology* 73: 1139–1147.
- Newbery RM, Wolfenden J, Mansfield TA, Harrison AF. 1995. Nitrogen, phosphorus and potassium uptake and demand in *Agrostis capillaris*: The influence of elevated CO<sub>2</sub> and nutrient supply. *New Phytol* 130: 565–574.
- Norby RJ, Jackson RB. 2000. Root dynamics and global change: Seeking an ecosystem perspective. *New Phytol* 147: 3–12.
- Paterson E, Hall JM, Rattray EA, Griffiths BS, Ritz K, Killham K. 1997. Effect of elevated CO<sub>2</sub> on rhizosphere carbon flow and soil microbial processes. *Global Change Biol* 3: 363–377.
- Pendall E, Bridgham S, Hanson PJ, Hungate B, Kicklighter DW, Johnson DW, et al. 2004. Below-ground process responses to elevated CO<sub>2</sub> and temperature: A discussion of observations, measurement methods, and models. *New Phytol* 162: 311–322.
- Perkins DF. 1968. Ecology of *Nardus stricta* L. annual growth in relation to tiller phenology. *J Ecol* 56: 633–646.
- Petit JR, Jouzel J, Raynaud D, Barkov NI, Barnola JM, Basile I, et al. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399: 429–436.
- Pregitzer KS, Hendrick RL, Fogel R. 1993. The demography of fine roots in response to patches of water and nitrogen. *New Phytol* 125: 575–580.
- Pregitzer KS, King JS, Burton AJ, Brown SE. 2000. Responses of tree fine roots to temperature. *New Phytol* 147: 105–115.
- Pregitzer KS, Laskowski MJ, Burton AJ, Lessard VC, Zak DR. 1998. Variation in sugar maple root respiration with root diameter and soil depth. *Tree Physiol* 18: 665–670.
- Reichle DE, Dinger BE, Edwards NT, Harris WF, Sollins P. 1973. In: Woodwell GM, Pecan EV, editors. *Carbon and the biosphere*. Brookhaven, NY: Atomic Energy Commission. pp. 345–365.
- Ross DJ, Tate KR, Newton PCD. 1995. Elevated CO<sub>2</sub> and temperature effects on soil carbon and nitrogen cycling in rye grass/white clover turves of an endoaquept soil. *Plant and Soil* 176: 37–49.
- Ryan MG. 1991. Effects of climate change on plant respiration. *Ecol Appl* 1: 157–167.
- Ryan MG, Hubbard RM, Pongracic S, Raison RJ, Mcmurtrie RE. 1996. Foliage, fine-root, woody-tissue and stand respiration in *Pinus radiata* in relation to nitrogen status. *Tree Physiol* 16: 333–343.
- Van der Westhuizen MM, Cramer MD. 1998. The influence of elevated rhizosphere dissolved inorganic carbon concentrations on respiratory O<sub>2</sub> and CO<sub>2</sub> flux in tomato roots. *J Exp Bot* 49: 1977–1985.
- Van Veen JA, Liljeroth E, Van de Lekkerkerk LJA, Geijn SC. 1991. Carbon fluxes in plant-soil systems at elevated atmospheric CO<sub>2</sub> levels. *Ecol Appl* 1: 175–181.
- Vogt KA, Persson H. 1991. Measuring growth and development of roots. In: Lassoie JP, Hinckley TM, editors. *Techniques and approaches in forest tree eco-physiology*. Boca Raton, FL: CRC Press. pp. 477–501.